

**A COMBINED MGII/CAII SURVEY OF STELLAR MAGNETIC
ACTIVITY IN THE SOLAR NEIGHBORHOOD**

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Low-Resolution *IUE* Observations of Chromospheric Mg II *h* and *k* Emission¹

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A Combined MgII/Ca II Survey of Stellar Magnetic Activity in the Solar Neighborhood

Nearly contemporaneous low-resolution IUE observations of Mg II h+k emission and Mount Wilson Observatory Ca II H+K fluxes were used for 33 pairs of observations of lower main-sequence stars to formulate a relationship that permits accurate predictions of Ca II H+K flux values as a function of a star's (B-V) color and Mg II h+k flux. The derived relationship is useful because it expands, by using the IUE observations of Mg II, the number of stars in the solar neighborhood for which a uniform estimate of chromospheric activity is available, including several solar-like stars that cannot be observed from the latitude of Mount Wilson Observatory. In addition, additional estimates of activity were derived for stars that have only been observed infrequently at Mount Wilson.

This calibration between the Mount Wilson observations and spectra from the IUE serves as the basis for additional studies utilizing data from the IUE Final Archive, when it has been constructed. We plan additional proposals in the future to concentrate on other types of stars using data for the Final Archive made available after the conclusion of this project.

A paper detailing our calibration and results is in preparation and will be submitted to the *Astrophysical Journal*. A poster paper showing interim results was presented at the AAS meeting in January, 1996 (B.W. Wicklund, R.A. Donahue, S. Baliunas, *Bulletin American Astron. Soc.*, 27, 1430 (1996)).

ABSTRACT

We use nearly contemporaneous low-resolution *IUE* observations of Mg II $h + k$ emission and Mount Wilson Observatory Ca II $H + K$ S indices for 33 pairs of observations of lower main sequence stars to formulate a relationship that will permit accurate predictions of S values as a function of $(B - V)$ color and Mg II $h + k$ flux. The resulting relationship is useful because it will extend the set of solar neighborhood stars for which a uniform estimate of chromospheric activity is available to include stars that are not observable from Mount Wilson as well as providing additional estimates of activity levels for stars that are on the Mount Wilson HK Project observing list.

Subject headings: stars: activity — stars: late-type

1. Introduction

Magnetic activity is ubiquitous among stars on the cool side of the Hertzsprung-Russell diagram. Such activity may be studied with the help of diagnostics such as the emission in the line cores of the resonance lines of singly ionized Mg and Ca. In particular, Ca II $H + K$ emission from lower main sequence stars has been studied systematically for many years. The HK Project at Mount Wilson Observatory (MWO) began with the establishment in 1966 by Olin Wilson of a program to measure Ca II $H + K$ fluxes for 91 lower main sequence stars on a regular basis (Wilson 1968). Near-nightly observations of many stars have been made at MWO since 1980, revealing, among other things, rotational modulation and activity cycles, for stars with a range of $(B - V)$ color (i.e., mass) (see, e.g., Noyes et al. 1984, Baliunas et al. 1995).

Previous studies (e.g., Oranje & Zwaan 1985, Schrijver 1987) have shown that radiative fluxes from various emission lines formed in the outer atmospheres of lower main sequence stars are highly correlated, although also dependent on mass, which can be represented by $(B - V)$ color. [do you want to go into why?, i.e., convective zone depth and effective temperature?]

The *International Ultraviolet Explorer (IUE)*, launched in 1978, has measured the UV spectra of over 700 G–M-type lower main-sequence stars. Boggess et al. (1978a, b) describe the spacecraft and its performance. The NASA Data Archive and Distribution Service (NDADS) has been developing a final archive of *IUE* data, the result of which has been improved signal-to-noise ratios and photometric accuracy and increased uniformity of the data set.

The resonance lines of Mg II, formed at heights similar to Ca II $H + K$, are also useful activity diagnostics. In particular, there are *IUE* observations for many stars that have are not a part of the HK Project data base. For less active stars, Mg is useful because the

photospheric line wings are darker at 280 nm and interpretation thus more straightforward than for Ca $H + K$. Using high resolution *IUE* data, Schrijver et al. (1992) established a relationship between Ca II fluxes and Mg II fluxes for stars with $0.5 \leq (B - V) \leq 1.0$. High resolution *IUE* observations, while desirable, are available for fewer stars than low-resolution observations, however. Given this, Hartmann et al. (1984) examined the relationship between Mg $h + k$ and rotation, demonstrating that Mg $h + k$ emission is fairly well correlated with Ca $H + K$ emission.

Low-resolution *IUE* data are now readily available for a larger sample of stars. Using this sample, we have determined a relationship between Mg II and Ca II emission that will allow us to predict values of Ca IIS. This in turn will expand the set of chromospheric activity indices for stars in the solar neighborhood sample (Vaughan & Preston 1980).

2. Observational Data

2.1. *IUE* Mg II observations

We have identified all available low-resolution spectra made by *IUE*'s Long Wavelength Prime (LWP) camera / spectrograph combination between 1978 and 1990 of lower main-sequence stars which are already in the *IUE* final archive and for which MWO Ca II observations have also been made. More recent LWP images, and, in particular, high-resolution spectra, are expected to be available from NDADS in the near future. From each image we extracted the flux measurements in three bandpasses: a 3-nm-wide passband, hk , centered at 279.9 nm, which contains both the Mg II h and k lines (located at 279.55 and 280.27 nm, respectively), and two 2-nm bands, v and r , located on the violet and red sides, respectively, of the hk band. These are the same bandpasses used successfully by Fanelli et al. (1990) to measure Mg II chromospheric emission. From these fluxes we

constructed an index s , dividing the flux in the hk bandpass by the sum of the fluxes in the two pseudo-continuum bands:

$$s = hk/(v + r). \quad (1)$$

The parameter s provides a measure of the Mg II flux relative to the surrounding continuum and is similar to the construction of the MWO Ca II S index (see below). Because of the low resolution of the instrument (NNN [?]nm) the s index contains a greater contribution from the photospheric continuum than does the S index. [*sure* this is true?]

2.2. MWO Ca II S indices

Comparison Ca II $H + K$ observations have been taken from the MWO HK Project data set and were made either with the coudé scanner on the 100-inch telescope (Wilson 1968) or with the HKP2 spectrophotometer on the 60-inch telescope (Vaughan et al. 1978, Baliunas et al. 1995). The present system permits the selection of either 0.1 nm- or 0.2 nm-wide slits for the H & K lines, centered at 396.8 and 393.4 nm, respectively. A chopper wheel sequentially measures the flux in the $H + K$ bandpasses and two 2-nm bandpasses, V and R , centered at 390.1 and 400.1 nm. The exit slits are translated to correct for a star’s velocity relative to the Earth. Several nightly observations of a standard lamp and of standard stars permit photometric calibration. The activity index S is defined as

$$S = \alpha \frac{(H + K)}{(V + R)}, \quad (2)$$

the ratio of the counts in the Ca II passbands to the sum of the counts in the pseudo-continuum bands; α is the nightly calibration factor. The integration times are determined such that the uncertainty due to the photon statistics is on the order of 1.0 – 1.5%.

3. Analysis

We have identified 33 pairs of observations in which *IUE* Mg II observations were made within 6 days of a corresponding MWO Ca II observation. While a larger data sample would be helpful, observations also need to be nearly contemporaneous to reduce the scatter in the relationship between Ca II S and Mg II s due to changes in a star’s level of activity over time. (Six days is arbitrary: we compared each *IUE* observation with the MWO observation closest to it in time; the distribution of time differences (Δt ’s) has a distinct break between 6 and 11 days.) Table 2 lists the values of Ca II S , Mg II s , Δt , and $(B - V)$ for these 33 pairs of observations.

EDITOR: PLACE TABLE ?? HERE.

Figure 1 shows the distribution of Ca S values *vs.* a) Mg s and b) $(B - V)$. Correlation coefficients between the variables are given in Table 1.

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We have fit MWO Ca II S as a function of *IUE* Mg s and $(B - V)$ using a linear least squares routine, including terms (and cross-terms) to third order in the independent variables. As each independent variable is considered an F -test is performed, and only those variables which contribute significantly to improving the percentage of the variance in the data which can be accounted for by the fit (i.e., $F \geq 3$) are retained. Due to the broader range of activity levels for later-type stars, we found it impractical to fit the entire $(B - V)$ range (0.42 – 1.37) with one fit and so split the data set into two parts, with some overlap, constructing separate fits for stars with $(B - V) \leq 0.9$ and $(B - V) \geq 0.8$.

For $(B - V) < 0.85$,

$$S_{predicted} = -0.310 + 1.362s^2 + 3.270(B - V)^2 - 3.570(B - V)^3, \quad (3)$$

and for $(B - V) \geq 0.85$,

$$S_{predicted} = -0.684 + 7.769s - 9.986s(B - V) + 3.394s(B - V)^2. \quad (4)$$

The former fit accounts for 87.0% of the variance for 28 points, with a multiple correlation coefficient, r , = 0.933; the latter fit accounts for 90.9% of the variance, with 18 points and $r = 0.953$. Figure 2 shows the residuals as functions of Mg II s and $B - V$.
[insert another figure here somehow]

The data set includes also 92 other observational pairs for which $\Delta t > 6$ days. We applied the relationship, determined above, to the *IUE* Mg II s values for these stars. In some cases the time difference between the *IUE* and MWO observations is several years, and therefore we would not expect to reproduce the observed Ca II S value precisely, but rather would expect to obtain a predicted S value that would fall within the range of values that might be expected for that star. Because we are investigating the possibilities of using low-resolution observations we have not attempted to model and subtract the photospheric contribution between the h and k lines. We find that for several very inactive stars in the high $(B - V)$ group, stars with Mg II s values well below any in the group from which the relationship was constructed, this results in predictions of negative Ca II S values. In other words, there is an empirical lower limit Mg II s envelope, as a function of $(B - V)$, below which we are not able to produce a useful relationship between Ca II S and (Mg II s , $(B - V)$).

For $(B - V) \geq 0.85$, the lower limit for application of the above relationship is

$$s = -1.967 + 3.306(B - V) - 1.829(B - V)^3 + 1.252(B - V)^4. \quad (5)$$

With the exception of those half-dozen stars, however, the predicted values of Ca II S for these non-contemporaneous observations are quite reasonable. Figure 3 w/ Mg II s vs $(B - V)$ showing lower limit and the non-contemp and non-MWO Mg II s , and the residuals for the non-contemp obs vs $(B - V)$.

4. Discussion

Equation 3 provides a method of converting Mg s values, derived from low-resolution spectra, into reasonably reliable Ca S values. From the non-contemporaneous observations we estimate that precision with which Ca II S is estimated from the low-resolution *IUE* observations is about 5% [CHECK THIS], i.e., roughly the uncertainty that would be expected taking any single instantaneous measurement without any knowledge of the particular circumstances of a star’s activity or variability. Thus it is possible for researchers to use low-resolution *IUE* data to predict S -index values for stars for which direct MWO observations are not possible. This significantly expands the number of stars in the solar neighborhood for which estimates of chromospheric magnetic activity are available.

5. Acknowledgements

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Table 1. Correlation Matrix

	Mg s	($B - V$)	Ca S
Mg II s	1.00	0.86	0.81
($B - V$)		1.00	0.76
Ca II S			1.00

Table 2. Data

HD	Ca II <i>S</i>	Mg II <i>s</i>	Δt (days)	(<i>B</i> – <i>V</i>)
10780	0.245	0.482	1.93	0.81
10780	0.245	0.456	1.98	0.81
17925	0.621	0.682	0.63	0.87
17925	0.591	0.725	0.86	0.87
22049	0.520	0.741	0.04	0.88
22049	0.525	0.768	0.16	0.88
22049	0.542	0.778	0.19	0.88
22049	0.567	0.756	0.69	0.88
22049	0.442	0.718	1.06	0.88
22049	0.442	0.729	1.10	0.88
22049	0.490	0.709	1.85	0.88
22049	0.426	0.701	2.80	0.88
26965	0.229	0.541	1.12	0.82
26965	0.229	0.513	1.21	0.82
26965	0.228	0.533	1.92	0.82
26965	0.228	0.529	1.95	0.82
35171	1.183	1.924	0.26	1.09
72905	0.364	0.416	3.99	0.62
103095	0.180	0.294	0.42	0.75
114710	0.191	0.321	2.44	0.57
115043	0.319	0.363	1.49	0.60
141004	0.154	0.299	0.47	0.60
142373	0.143	0.244	0.50	0.56
166620	0.175	0.527	2.87	0.87

Table 2—Continued

HD	Ca II <i>S</i>	Mg II <i>s</i>	Δt (days)	(<i>B</i> – <i>V</i>)
185144	0.184	0.393	2.85	0.80
187691	0.153	0.297	0.08	0.55
166620	0.175	0.532	2.60	0.87
201091	0.660	1.683	0.77	1.18
201091	0.660	2.100	0.81	1.18
201091	0.597	1.910	4.86	1.18
201092	0.990	3.608	4.83	1.37
206860	0.334	0.354	4.85	0.59
207978	0.148	0.314	5.73	0.42

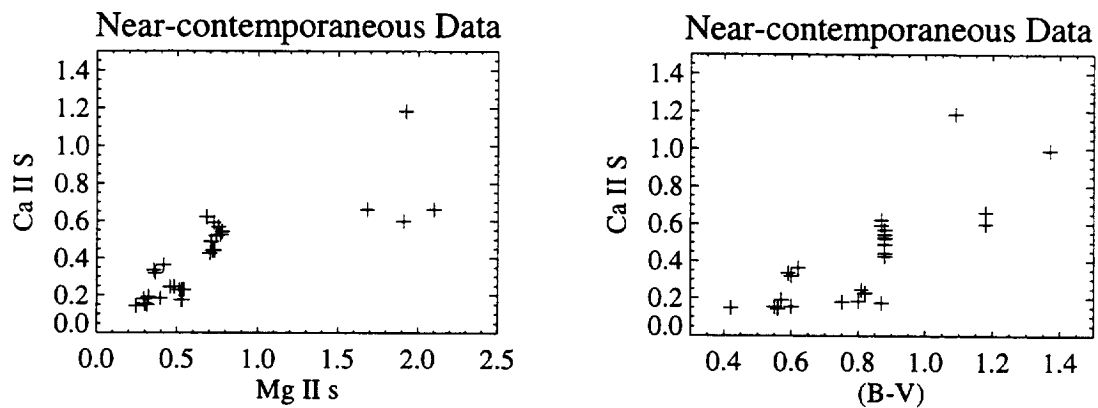


Fig. 1.— Near-contemporaneous Data; a) MWO Ca II S vs. IUE Mg II s for 33 observation pairs; b) the distribution of MWO Ca II S vs. $(B - V)$ color for these observations.

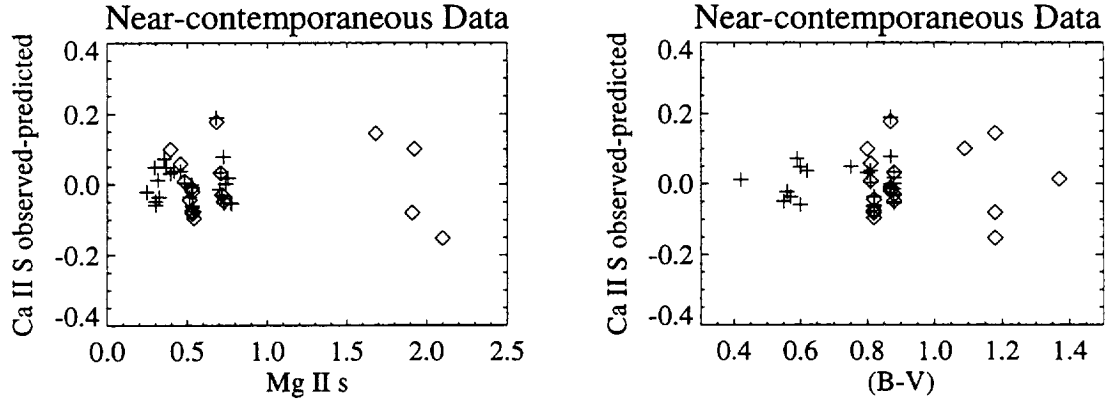


Fig. 2.— The residuals for the 33 nearly contemporaneous observations used in the linear least squares fits vs. a) *IUE* Mg II *s* and b) $(B - V)$ color. The + symbols are for the low- $(B - V)$ fit, the diamonds for the high- $(B - V)$ fit.

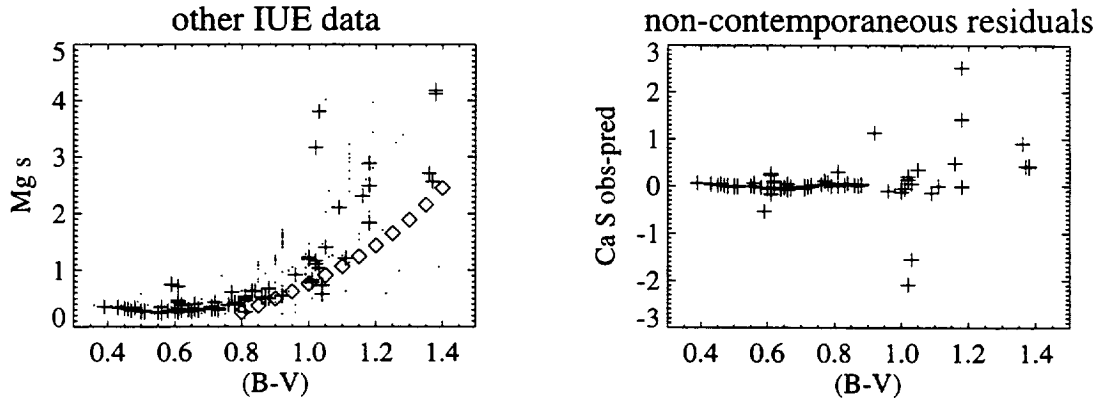


Fig. 3.— Predicted Ca II S values for other *IUE* observations. In a) the + symbols are the *IUE* data for which non-contemporaneous MWO observations exist, the small dots are *IUE* observations for which there are no corresponding MWO, and the diamonds indicate the lower limit of fit applicability. The residuals obtained by applying the predictive fit to the *IUE* data for which non-contemporaneous MWO observations exist are shown in b).